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Shot-Peening Sensitivity of Aluminum With Corrosion-Preventive Coatings

by Scott Grendahl and Daniel Snoha

ARL-TR-4304 November 2007

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Weapons and Materials Research Directorate, ARL

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14. ABSTRACT The U.S. Army Aviation and Missile Research, Development, and Engineering Center Aviation Engineering Division (Huntsville, AL) requested that the U.S. Army Research Laboratory Weapons and Materials Research Directorate (Aberdeen Proving Ground, MD) execute a program aimed at evaluating the shot-peening sensitivity of 7075-T73 aluminum with U.S. Army corrosion-preventive coatings for aluminum. The coatings represent the two most common coatings for aviation aluminum alloys. The study was a follow-up to previous work that investigated shot-peening sensitivity on the base material. During that study, it was discovered that the aluminum alloy showed decreased fatigue strength when shot-peened at high Almen intensities. The present study focuses on the shot-peening interaction with the coatings. Both studies develop data to correlate surface roughness, x-ray diffraction residual stress analysis, and fatigue strength at a prescribed stress intensity, $K_t = 1.75$.					
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1. Introduction

The U.S. Army Aviation and Missile Research Development and Engineering Command (AMRDEC) Aviation Engineering Division (Huntsville, AL) requested that the U.S. Army Research Laboratory (ARL) Weapons and Materials Research Directorate (Aberdeen Proving Ground, MD) execute a program aimed at evaluating the shot-peening sensitivity of 7075-T73 aluminum with U.S. Army corrosion-preventive coatings for aluminum. The coatings represent the two most common coatings for aviation aluminum alloys. The study was a follow-up to previous work that investigated shot-peening sensitivity on the base material. During that study, it was discovered that the aluminum alloy showed decreased fatigue strength when shot-peened at high Almen intensities. The present study focuses on the shot-peening interaction with the coatings. Both studies develop data to correlate surface roughness, x-ray diffraction residual stress analysis (XRD-RSA), and fatigue strength at a prescribed stress intensity, $K_t = 1.75$.

2. Objective

Our objective was to assess the sensitivity of shot-peening in conjunction with corrosion-preventive coatings on 7075-T73 aluminum at stress intensity $K_t = 1.75$.

3. Materials

AMRDEC and ARL selected the materials used in this test program based upon the results of the previous study.[1] Aluminum 7075-T73 was selected because of the fatigue strength decrease observed at higher Almen intensities. The material mechanical properties and specifications are described in table 1. The heat lot of material utilized was identical to that in the previous work. The corrosion-preventive coating systems for the aluminum are defined in table 2.

[1]Grendahl, S.; Snoha, D.; Hardisky, B. *Shot Peening Sensitivity of Aerospace Materials;* ARL-TR-4095; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

Table 1. Material.

Material	Specification	Material Strength Supplier (ksi)	Material Strength ARL Tested (ksi)	Material Hardness
Aluminum 7075-T73	AMS-QQ-A 225/9[a]	77.6 UTS 67.0 YS	80 UTS 71 YS	80-81 HRB

[a]AMS-QQ-A 225/9. *Aluminum Alloy 7075 Bar, Rod, Wire, and Special Shapes, Rolled, Drawn, or Cold Finished* **1997**.
Notes: UTS = ultimate tensile strength, and YS = yield strength.

Table 2. Corrosion-preventive coating systems.

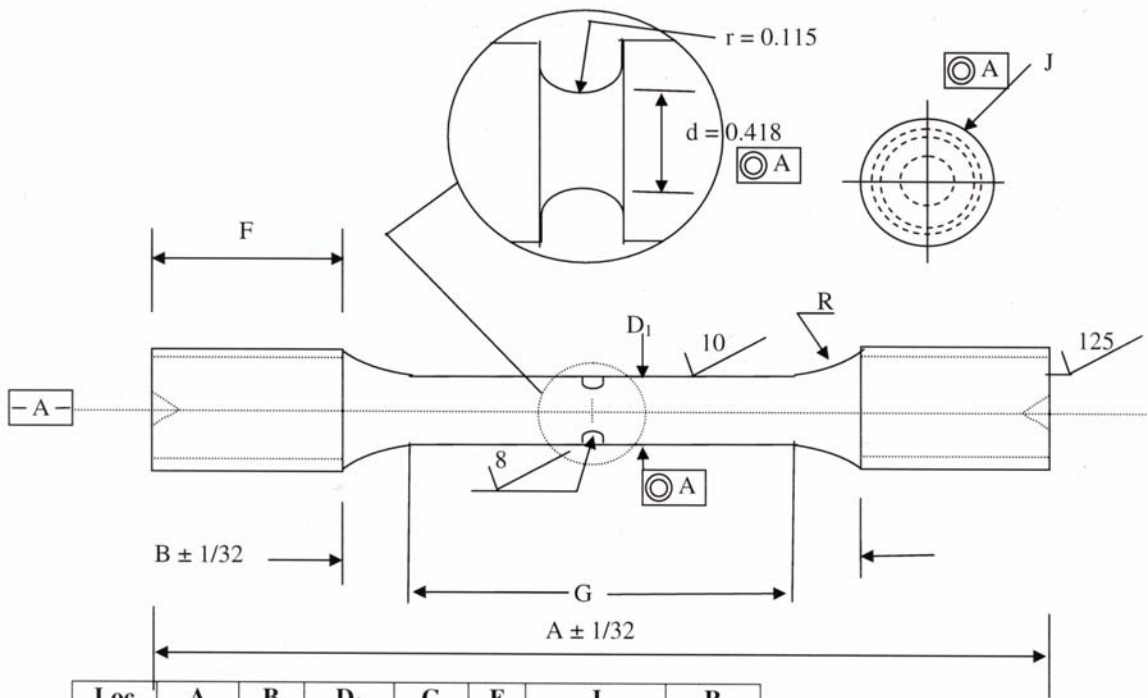
Coating	Specification	Type	Class	Acid
Alodine	MIL-DTL-5541[a]	Type I	1A	Chromic
Anodize	MIL-A-8625F[b]	Type I	1	Chromic

[a]MIL-DTL-5541F. *Chemical Conversion Coatings and Aluminum Alloys* **2006**.
[b]MIL-A-8625F. *Anodic Coatings for Aluminum and Aluminum Alloys* **1993**.

4. Experimental Procedure

4.1 Fatigue

For the fatigue strength assessment, one stress intensity, Kt = 1.75 was utilized, based upon the worst case of fatigue strength drop-off from the previous work.[1] Figure 1 presents the schematic for the specimens utilized. This specimen geometry was approved through AMRDEC. Appendix F fully outlines the final fatigue test plan as approved by AMRDEC. Table 3 presents the test matrix for the program. Specimens were shot-peened by Metal Improvement Company (MIC), based upon the capabilities of the vendor, their prior involvement with the previous work, and the test requirements at the discretion of AMRDEC. Fatigue testing was carried out where the previous work's aluminum specimens had been tested and on the identical mechanical test frame with the identical fixtures. A 20-kip Instron Model 1350 test frame with a 10-kip load cell was utilized. The test frame was calibrated by the vendor in the summer of 2006. Tests were performed with sinusoidal oscillation at a frequency of 20 Hz and at an R-ratio, minimum to maximum stress, of 0.1. A Nicolet model 4094 C oscilloscope was utilized to optimize the conditions of the sinusoidal wave and loop-shaping parameters of the closed-loop feedback systems on the test frame hardware. All tests were conducted at room temperature in air. The run-out stop point was agreed upon to be 2-million cycles. All run-outs were at least this duration; however, weekends and holidays were utilized to their fullest extent, and some run-outs were of greater duration. Figure 2 depicts the typical experimental setup for this work.



Loc	A	B	D_1	G	F	J	R
	4-1/4	2.5	0.670	2.00	7/8	1.0-16-2A	0.275

Notes:
1. Dimensions in Inches
2. Tolerances
   a. Squareness $\perp$ perpendicular ± 0.001 TIR
      ‖ Parallel ± 0.001 TIR
   b. Diameters ◎ Concentric to – A – ± 0.001 TIR
   c. Fractional ± 1/64
   d. Decimal X.XX ± 0.005
      X.XXX ± 0.001
      X.XXXX ± 0.0005

Figure 1. Schematic of the aluminum Kt = 1.75 specimens.

Table 3. Fatigue test matrix for 7075-T73 alloy.

Peening Intensity	Shot Peen Source(s)	Anodize Coating	Alodine Coating	Re-Peen Anodize Surface, Then Alodine
Unpeened	NA	10	10	NA
4A ± 0.5A	MIC	10	10	10
12A ± 0.5A	MIC	10	10	10

Note: NA = not applicable.

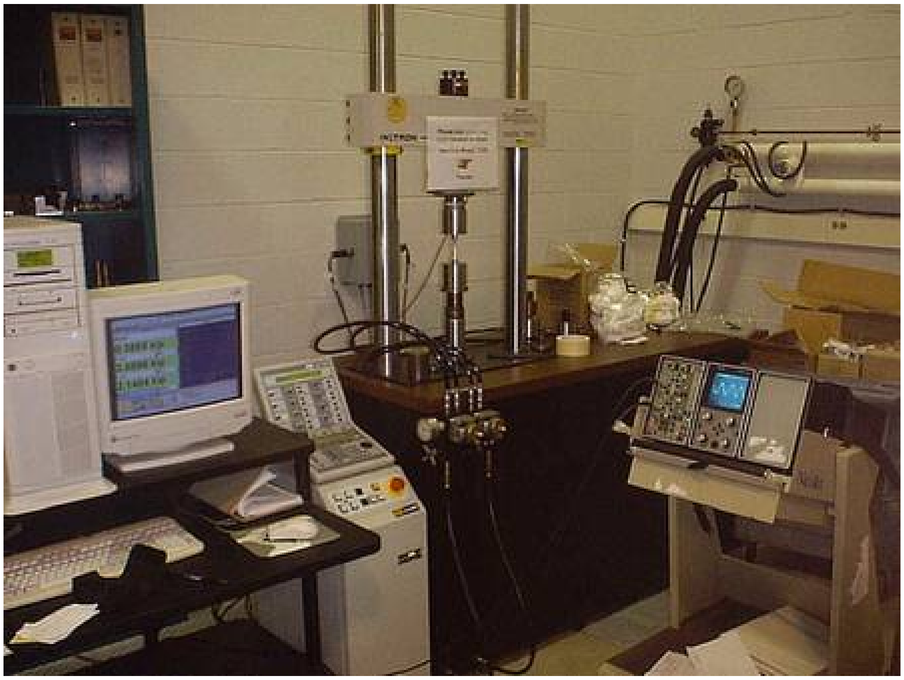


Figure 2. Experimental test setup for aluminum.

4.2 XRD-RSA

A Technology for Energy Corporation (TEC) model 1610 x-ray stress analysis system, employing the $\sin^2\psi$ technique, was used for measuring residual stress (strain) on the unpeened and peened fatigue specimens. Based on linear elasticity theory, the nondestructive XRD-RSA method is capable of determining the strain induced in the surface layers of a crystalline material as a consequence of mechanical deformation processes such as machining or shot-peening. All residual stress data were collected from a four- or seven-positive ψ angle arrangement, and CuKα radiation diffracted from the (333,511) lattice planes of the aluminum. The incident x-ray beam was collimated to provide a 2- × 5-mm rectangular irradiated area on the fatigue specimens, with the longer dimension aligned axially. Measurements were made on the fatigue specimens 0.45 in from the notch at an arbitrarily chosen 0° orientation and 120° from that location. Residual stresses were measured only at the surface on the fatigue specimens. The x-ray elastic constants required to calculate the macroscopic residual stress from the measured strain were in agreement with common practice. The experimental setup and the TEC equipment can be observed in figure 3.

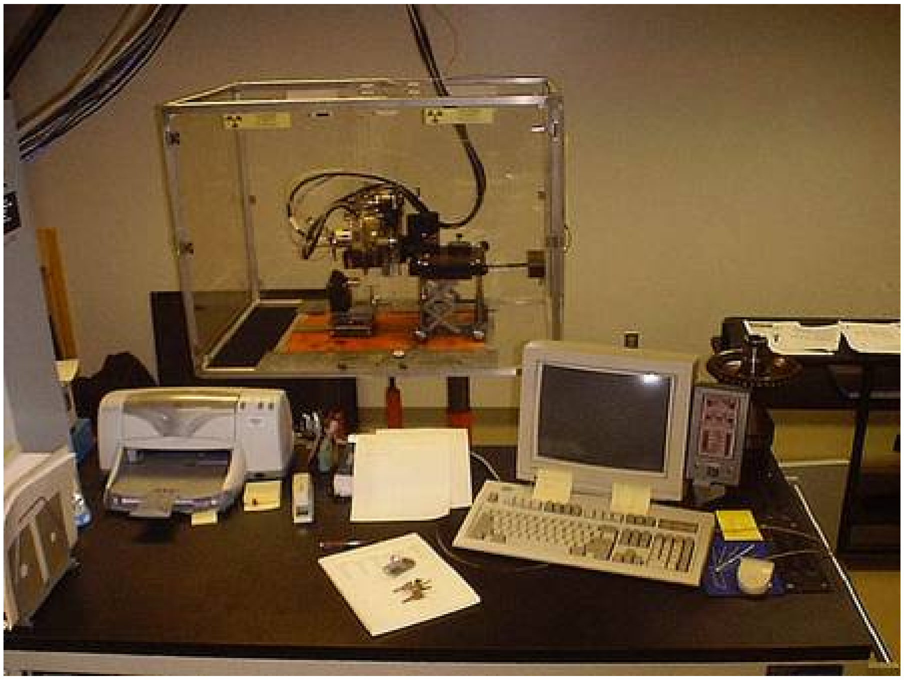


Figure 3. Experimental setup and equipment utilized for XRD-RSA.

4.3 Surface-Roughness Assessment

A Taylor-Hobson Form TalySurf Series 2 was utilized to perform laser surface profilometry of the fatigue specimen. Measurements were acquired for each peening intensity and coating combination as well as the unpeened condition. Two $K_t = 1.75$ specimens from each group were selected to obtain surface-roughness data. The specimens chosen were identical to the ones in the XRD-RSA section. Three linear measurements were acquired at 120° increments around the circumference in the peened area. The data were acquired along the outside diameter, not within the notch. The notched area proved too small to allow the laser surface profilometer head adequate room to function properly. Ninety-six measurements were acquired. The experimental setup can be observed in figure 4.

5. Results

5.1 Fatigue

The results of the fatigue testing portion of this study are presented in tabular and graphic form. Table 4 presents the cyclic fatigue data for 7075-T73 aluminum $K_t = 1.75$ specimens. A graphical representation of the data is depicted in figure 5.

Figure 4. Experimental setup and equipment utilized for surface-roughness analysis.

5.2 XRD-RSA

The results of the XRD-RSA analysis are presented in tabular and graphical form. Table 5 presents the observed (as-collected) XRD-RSA acquired during this investigation from 7075-T73 aluminum fatigue specimens. Figure 6 presents the data as groups of bare specimens, anodized specimens, and alodined specimens, according to the shot-peening intensity and coating characteristics. The error in the observed residual stress data for the different fatigue specimens is also listed in table 5. This error is the larger value of either the counting statistics error or the probable error, both of which are generated for each measurement from statistical error analysis. Counting statistics error results from the statistical nature of the x-rays counted in the detector. Probable error is due to metallurgical and stress effects and systematic error.

5.3 Surface Roughness

The results of the surface-roughness assessment of the study are presented in table 6 for aluminum 7075-T73 alloy. The same specimens from the XRD-RSA collected data were utilized for the measurements. Groups were created from shot-peening intensity and corrosion-preventive coating type. Ra values and RMS values were calculated from the raw collected data.

Table 4. Cyclic fatigue data for 7075-T73 anodized and alodined aluminum K_t = 1.75.

Specimen Number	Vendor	Shot-Peening Intensity	Maximum Stress	Mean Stress	Minimum Stress	Stress Amplitude	R	Cycles	Notes
Al-1-C	MIC	4A-AN	28.00	15.400	2.80	12.6	0.1	201,292	
Al-2-C	MIC	4A-AN	26.00	14.300	2.60	11.7	0.1	2,000,000	Runout
Al-3-C	MIC	4A-AN	24.00	13.200	2.40	10.8	0.1	2,951,992	Runout at 24 ksi
Al-3-C	MIC	4A-AN	35.00	19.250	3.50	15.75	0.1	65,671	—
Al-4-C	MIC	4A-AN	26.50	14.575	2.65	11.925	0.1	550,350	—
Al-5-C	MIC	4A-AN	26.75	14.713	2.68	12.0375	0.1	316,350	—
Al-6-C	MIC	4A-AN	27.00	14.850	2.70	12.15	0.1	319,847	—
Al-7-C	MIC	4A-AN	30.00	16.500	3.00	13.5	0.1	102,338	—
Al-8-C	MIC	4A-AN	33.00	18.150	3.30	14.85	0.1	122,627	—
Al-9-C	MIC	4A-AN	26.50	14.575	2.65	11.925	0.1	2,276,559	Runout
Al-10-C	MIC	4A-AN	28.00	15.400	2.80	12.6	0.1	186,786	—
Al-11-C	MIC	4A-AL	28.00	15.400	2.80	12.6	0.1	172,568	—
Al-12-C	MIC	4A-AL	26.00	14.300	2.60	11.7	0.1	2,171,008	Runout
Al-13-C	MIC	4A-AL	28.00	15.400	2.80	12.6	0.1	262,438	—
Al-14-C	MIC	4A-AL	27.00	14.850	2.70	12.15	0.1	271,534	—
Al-15-C	MIC	4A-AL	26.50	14.575	2.65	11.925	0.1	282,621	—
Al-16-C	MIC	4A-AL	26.50	14.575	2.65	11.925	0.1	165,832	—
Al-17-C	MIC	4A-AL	26.50	14.575	2.65	11.925	0.1	2,887,521	Runout
Al-18-C	MIC	4A-AL	35.00	19.250	3.50	15.75	0.1	81,792	—
Al-19-C	MIC	4A-AL	27.00	14.850	2.70	12.15	0.1	230,275	—
Al-20-C	MIC	4A-AL	30.00	16.500	3.00	13.5	0.1	85,881	—
Al-21-C	MIC	4A-AN-4A-AL	28.00	15.400	2.80	12.6	0.1	1,101,734	—
Al-22-C	MIC	4A-AN-4A-AL	38.00	20.900	3.80	17.1	0.1	40,880	—
Al-22-C	MIC	4A-AN-4A-AL	26.00	14.300	2.60	11.7	0.1	2,010,910	Runout at 26 ksi
Al-23-C	MIC	4A-AN-4A-AL	26.50	14.575	2.65	11.925	0.1	1,890,040	—
Al-24-C	MIC	4A-AN-4A-AL	36.00	19.800	3.60	16.2	0.1	88,309	—
Al-25-C	MIC	4A-AN-4A-AL	34.00	18.700	3.40	15.3	0.1	136,637	—
Al-26-C	MIC	4A-AN-4A-AL	26.50	14.575	2.65	11.925	0.1	2,000,000	Runout
Al-27-C	MIC	4A-AN-4A-AL	28.00	15.400	2.80	12.6	0.1	2,167,543	Runout
Al-28-C	MIC	4A-AN-4A-AL	27.00	14.850	2.70	12.15	0.1	6,377,998	Runout at 27 ksi
Al-28-C	MIC	4A-AN-4A-AL	29.00	15.950	2.90	13.05	0.1	297,257	—
Al-29-C	MIC	4A-AN-4A-AL	32.00	17.600	3.20	14.4	0.1	241,061	—
Al-30-C	MIC	4A-AN-4A-AL	30.00	16.500	3.00	13.5	0.1	268,673	—
Al-31-C	MIC	12A-AN	38.00	20.900	3.80	17.1	0.1	74,245	—
Al-32-C	MIC	12A-AN	32.00	17.600	3.20	14.4	0.1	132,243	—
Al-33-C	MIC	12A-AN	34.00	18.700	3.40	15.3	0.1	154,407	—
Al-34-C	MIC	12A-AN	30.00	16.500	3.00	13.5	0.1	236,991	—
Al-35-C	MIC	12A-AN	30.00	16.500	3.00	13.5	0.1	178,769	—
Al-36-C	MIC	12A-AN	29.00	15.950	2.90	13.05	0.1	3,907,331	—
Al-37-C	MIC	12A-AN	34.00	18.700	3.40	15.3	0.1	143,989	—
Al-38-C	MIC	12A-AN	32.00	17.600	3.20	14.4	0.1	118,768	—
Al-39-C	MIC	12A-AN	40.00	22.000	4.00	18	0.1	64,950	—
Al-40-C	MIC	12A-AN	30.00	16.500	3.00	13.5	0.1	2,000,000	Runout
Al-41-C	MIC	12A-AL	28.00	15.400	2.80	12.6	0.1	2,876,686	Runout
Al-42-C	MIC	12A-AL	34.00	18.700	3.40	15.3	0.1	108,600	—
Al-43-C	MIC	12A-AL	38.00	20.900	3.80	17.1	0.1	75,765	—
Al-44-C	MIC	12A-AL	32.00	17.600	3.20	14.4	0.1	117,409	—
Al-45-C	MIC	12A-AL	30.00	16.500	3.00	13.5	0.1	191,928	—
Al-46-C	MIC	12A-AL	34.00	18.700	3.40	15.3	0.1	100,225	—
Al-47-C	MIC	12A-AL	32.00	17.600	3.20	14.4	0.1	205,544	—
Al-48-C	MIC	12A-AL	29.00	15.950	2.90	13.05	0.1	8,101,796	Runout
Al-49-C	MIC	12A-AL	30.00	16.500	3.00	13.5	0.1	3,023,342	Runout
Al-50-C	MIC	12A-AL	30.00	16.500	3.00	13.5	0.1	335,348	—
Al-51-C	MIC	12A-AN-12A-AL	40.00	22.000	4.00	18	0.1	52,650	—
Al-52-C	MIC	12A-AN-12A-AL	34.00	18.700	3.40	15.3	0.1	172,165	—
Al-53-C	MIC	12A-AN-12A-AL	30.00	16.500	3.00	13.5	0.1	182,101	—
Al-54-C	MIC	12A-AN-12A-AL	38.00	20.900	3.80	17.1	0.1	65,851	—
Al-55-C	MIC	12A-AN-12A-AL	32.00	17.600	3.20	14.4	0.1	140,401	—

Table 4. Cyclic fatigue data for 7075-T73 anodized and alodined aluminum K_t = 1.75 (continued).

Specimen Number	Vendor	Shot-Peening Intensity	Maximum Stress	Mean Stress	Minimum Stress	Stress Amplitude	R	Cycles	Notes
Al-56-C	MIC	12A-AN-12A-AL	30.00	16.500	3.00	13.5	0.1	4,808,706	Runout
Al-57-C	MIC	12A-AN-12A-AL	34.00	18.700	3.40	15.3	0.1	192,003	—
Al-58-C	MIC	12A-AN-12A-AL	32.00	17.600	3.20	14.4	0.1	191,245	—
Al-59-C	MIC	12A-AN-12A-AL	29.00	15.950	2.90	13.05	0.1	2,602,474	Runout
Al-60-C	MIC	12A-AN-12A-AL	30.00	16.500	3.00	13.5	0.1	599,385	—
Al-81-C	MIC	AN – good	19.00	10.450	1.90	8.55	0.1	381,731	—
Al-82-C	MIC	AN – good	24.00	13.200	2.40	10.8	0.1	65,824	—
Al-83-C	MIC	AN – good	26.00	14.300	2.60	11.7	0.1	65,983	—
Al-84-C	MIC	AN – good	18.00	9.900	1.80	8.1	0.1	598,075	—
Al-85-C	MIC	AN – good	18.50	10.175	1.85	8.325	0.1	456,023	—
Al-86-C	MIC	AN – good	20.00	11.000	2.00	9	0.1	222,764	—
Al-87-C	MIC	AN – good	26.00	14.300	2.60	11.7	0.1	71,216	—
Al-88-C	MIC	AN – good	19.00	10.450	1.90	8.55	0.1	301,828	—
Al-89-C	MIC	AN – good	22.00	12.100	2.20	9.9	0.1	113,191	—
Al-90-C	MIC	AN – good	22.00	12.100	2.20	9.9	0.1	116,883	—
Al-91-C	MIC	AL – good	35.00	19.250	3.50	15.75	0.1	16,956	—
Al-92-C	MIC	AL – good	24.00	13.200	2.40	10.8	0.1	2,006,330	Runout
Al-93-C	MIC	AL – good	28.00	15.400	2.80	12.6	0.1	108,576	—
Al-94-C	MIC	AL – good	28.00	15.400	2.80	12.6	0.1	107,084	—
Al-95-C	MIC	AL – good	26.00	14.300	2.60	11.7	0.1	195,519	—
Al-96-C	MIC	AL – good	24.00	13.200	2.40	10.8	0.1	159,733	—
Al-97-C	MIC	AL – good	26.00	14.300	2.60	11.7	0.1	195,034	—
Al-98-C	MIC	AL – good	24.00	13.200	2.40	10.8	0.1	319,212	—
Al-99-C	MIC	AL – good	25.00	13.750	2.50	11.25	0.1	279,437	—
Al-100-C	MIC	AL – good	31.00	17.050	3.10	13.95	0.1	52,798	—

Notes: AN = anodized, and AL = alodined.

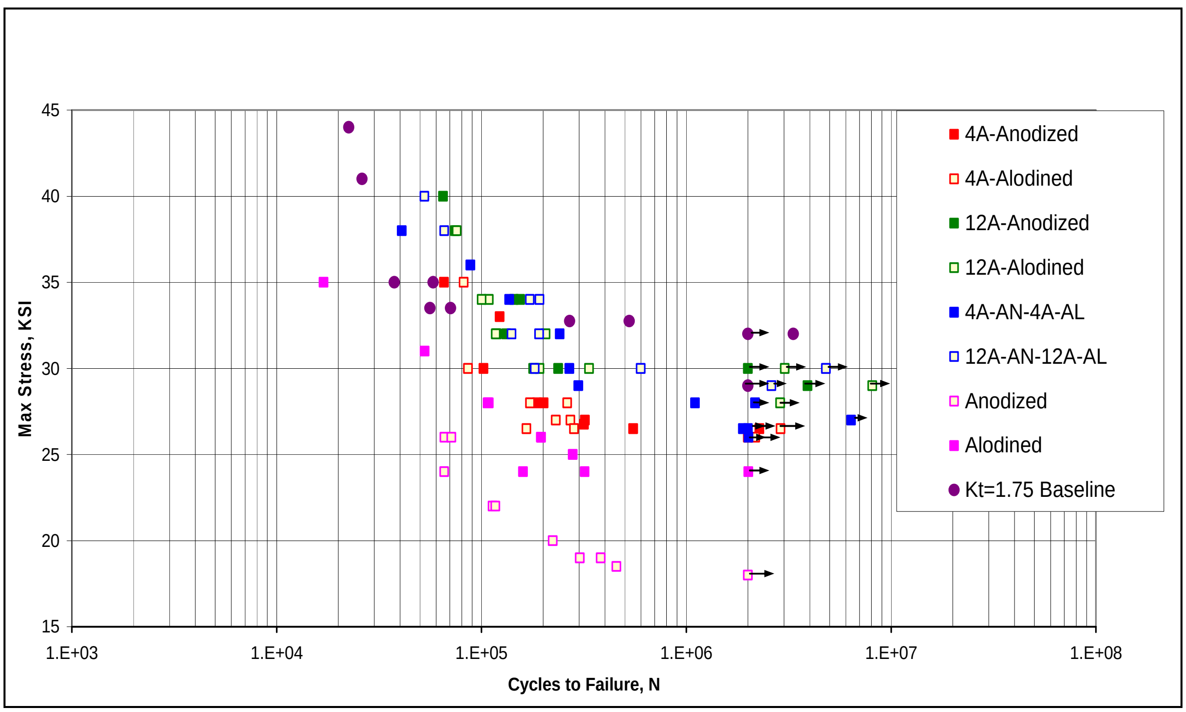


Figure 5. Graphical representation of cyclic fatigue data for 7075-T73 anodized and alodined aluminum K_t = 1.75.

Table 5. Fatigue specimen data for 7075-T73 aluminum XRD-RSA.

Specimen	Surface Condition	Orientation (°)	Stress (ksi)	Stress, (MPa)	Error (± ksi)	Error (± MPa)
5-Al-C	MIC-4A, AN	0	–42.5	–292.7	2.1	14.5
5-Al-C	MIC-4A, AN	120	–44.8	–308.7	1.9	13.1
8-Al-C	MIC-4A, AN	0	–42.5	–293.3	2.3	15.9
8-Al-C	MIC-4A, AN	120	–43.4	–299.0	2.5	17.2
15-Al-C	MIC-4A, AL	0	–46.1	–318.0	2.3	15.7
15-Al-C	MIC-4A, AL	120	–48.6	–334.9	2.4	16.5
18-Al-C	MIC-4A, AL	0	–42.1	–290.6	1.6	11.1
18-Al-C	MIC-4A, AL	120	–45.2	–311.9	2.6	17.6
24-Al-C	MIC-4A, AN, Re-peen at 4A, AL	0	–45.0	–310.2	1.3	8.6
24-Al-C	MIC-4A, AN, Re-peen at 4A, AL	120	–45.6	–314.6	1.6	11.2
27-Al-C	MIC-4A, AN, Re-peen at 4A, AL	0	–43.4	–299.4	0.7	4.6
27-Al-C	MIC-4A, AN, Re-peen at 4A, AL	120	–44.6	–307.6	1.2	8.0
37-Al-C	MIC-12A, AN	0	–35.6	–245.8	1.3	9.1
37-Al-C	MIC-12A, AN	120	–36.1	–248.6	0.9	6.3
40-Al-C	MIC-12A, AN	0	–32.6	–224.8	1.9	13.0
40-Al-C	MIC-12A, AN	120	–33.1	–228.0	1.6	11.1
42-Al-C	MIC-12A, AL	0	–30.2	–208.2	1.4	9.9
42-Al-C	MIC-12A, AL	120	–32.9	–226.5	1.7	11.4
45-Al-C	MIC-12A, AL	0	–33.0	–227.3	1.6	11.2
45-Al-C	MIC-12A, AL	120	–34.2	–236.0	1.3	9.1
55-Al-C	MIC-12A, AN, Re-peen at 12A, AL	0	–32.1	–221.2	1.3	8.9
55-Al-C	MIC-12A, AN, Re-peen at 12A, AL	120	–32.1	–221.4	1.5	10.3
59-Al-C	MIC-12A, AN, Re-peen at 12A, AL	0	–31.5	–217.0	1.4	9.9
59-Al-C	MIC-12A, AN, Re-peen at 12A, AL	120	–30.3	–208.7	1.6	11.2
84-Al-C	AN	0	–10.0	–68.9	2.6	18.2
84-Al-C	AN	120	–12.4	–85.2	1.2	8.0
85-Al-C	AN	0	–7.3	–50.1	2.3	15.8
85-Al-C	AN	120	–12.0	–82.5	1.6	11.2
96-Al-C	AL	0	–9.0	–61.8	1.6	10.9
96-Al-C	AL	120	–3.0	–20.6	2.5	17.3
100-Al-C	AL	0	–12.2	–83.9	1.0	7.2
100-Al-C	AL	120	–5.0	–34.7	1.3	8.8

Notes: AN = anodized, and AL = alodined.

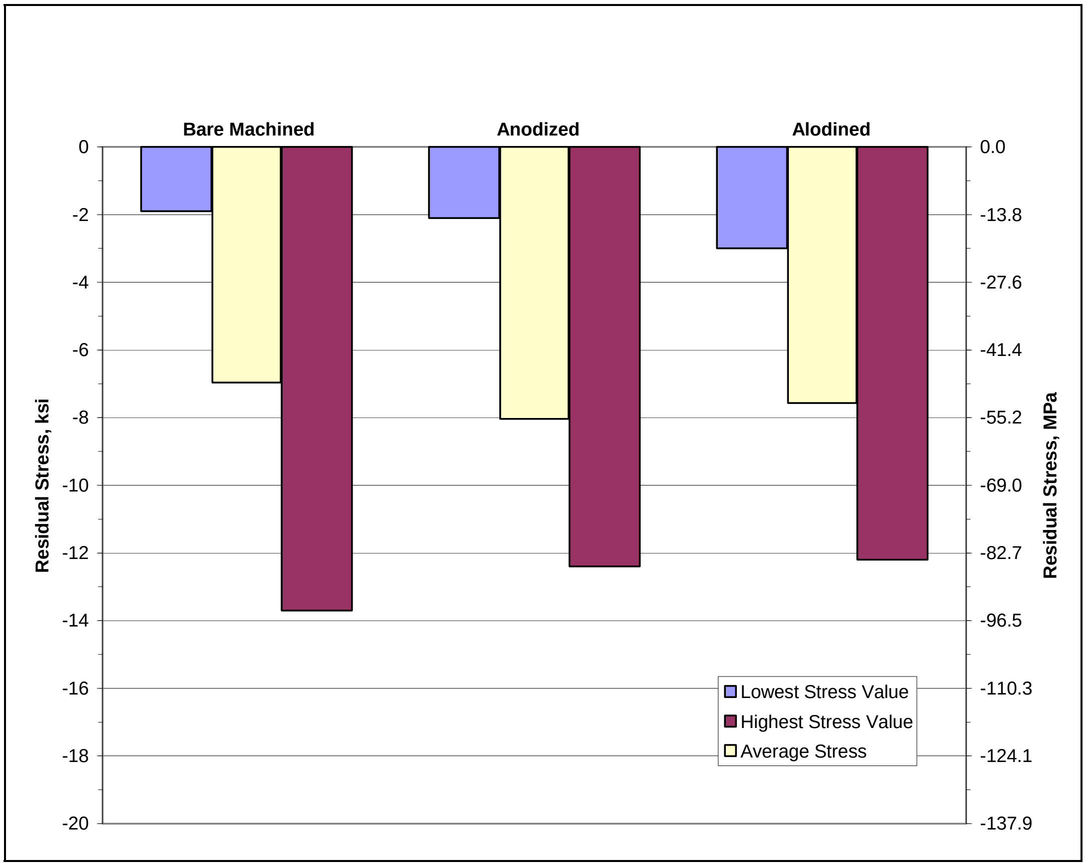


Figure 6. Graphical representation of 7075-T73 aluminium XRD-RSA.

Table 6. Aluminum surface-roughness data.

Group	Specimen Number	Location	Ra (µin)	RMS (µin)
4A then AN	5Al-C	A	166.9961	201.5276
		B	138.1732	175.8583
		C	144.185	181.5551
	8Al-C	A	143.9016	183.3031
		B	142.8307	179.0236
		C	144.3622	184.3976
4A then AL	15Al-C	A	159.3543	199.9921
		B	149.0709	183.8819
		C	147.4291	188.5512
	18Al-C	A	158.6614	198.1299
		B	146.9843	183.4134
		C	138.7323	174.5472
4A then AN, 4A then AL	24Al-C	A	136.5	169.0984
		B	138.1102	170.1969
		C	146.7638	186.3031
	27Al-C	A	137.2165	172.9882
		B	143.4528	183.0512
		C	152.0433	190.3543
12A then AN	37Al-C	A	315.0512	385.5748
		B	288.374	392.9134
		C	318.9016	398.2638
	40Al-C	A	264.4331	336.7205
		B	264.9646	324.063
		C	314.8346	387.3465
12A then AL	42Al-C	A	317.2835	406.6181
		B	285.4055	364.1732
		C	306.9961	393.063
	45Al-C	A	258.3898	315.2677
		B	308.8268	377.6339
		C	270.7283	324.6181
12A then AN then 12A then AL	55Al-C	A	332.3504	405.2913
		B	284.5827	361.6299
		C	296.1299	370.7087
	59Al-C	A	311.622	403.4646
		B	361.9488	466.1693
		C	299.1339	368.0748
AN	84Al-C	A	27.93701	34.68504
		B	25.73622	32.05906
		C	23.43307	30.24016
	85Al-C	A	27.83071	34.75984
		B	32.83858	41.54724
		C	32.47638	41.07087
AL	96Al-C	A	26.20079	32.88976
		B	26.70866	32.74016
		C	32.14961	40.02362
	100Al-C	A	22.50394	28.21654
		B	23.72835	30.12598
		C	25.09055	31.54724

Notes: AN = anodized, and AL = alodined.

6. Discussion

6.1 Fatigue

The fatigue performance of the various intensity groups varied significantly. The baseline bare aluminum group was the best overall performer in the high-cycle low-stress region, and the 12A Almen intensity shot-peening seemed to provide improvement in the high-stress low-cycle region. The unshot-peened alodized group fared the worst, falling just below the unshot-peened alodined group (as would be expected since anodizing is applied under a more severe process). The 4A Almen intensity results fell in the middle of the data spread.

6.2 XRD-RSA

The bare alodized and alodined groups appeared to have the least residual stress (~–10 ksi), as was expected, while the 4A Almen intensity group appeared to have the most (~–45 ksi). Curiously, the 12A Almen intensity group was in the middle with ~–33 ksi, on average. There was uniform, but low, error observed across all groups and an approximately equal spread in the data.

6.3 Surface Roughness

The surface roughness of the aluminum specimens demonstrated good agreement across all groups. This data set compared reasonably well with the data from the previous work. The bare (no shot-peening) machined samples had an ~30-µin surface finish, the 4A specimens had an ~140-µin surface finish, and the 12A specimens had an ~300-µin surface finish. There seemed to be no discernable difference in surface roughness between the alodined and anodized groups, regardless of shot-peening intensity.

7. Conclusions

7.1 Fatigue

1. Fatigue performance of specimens varied significantly with shot-peening intensity, while only slightly with either corrosion-preventive coating treatment.

2. Anodizing and alodining appear to greatly reduce the fatigue strength of the material. This reduction was regained by applying shot-peening at the 12A intensity level.

3. It appears that the repair simulation of anodizing then alodining with redundant stages of shot-peening at a specified intensity does not deleteriously affect the fatigue resistance.

4. In the majority of cases, the lowest fatigue strength was demonstrated from the anodization process.

7.2 XRD-RSA

1. The magnitude of the residual stresses measured at the 0° and 120° orientations on the shot-peened fatigue specimens was approximately equivalent.

2. The maximum compressive residual stress was measured on the shot-peened disk specimens from the 4A shot-peening-intensity group.

3. There was no discernable difference between the corrosion-preventive coating groups at equivalent shot-peening intensities.

7.3 Surface Roughness

1. There existed a direct relationship between shot-peening intensity and surface roughness. The greater the peening intensity, the greater the resultant surface roughness.

2. There appeared to be disagreement between the surface-roughness data and the XRD-RSA data. The roughest group (12A) did not have the highest degree of residual compressive stress.

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Appendix A. Add Test Matrix for Aluminum Alloy With Surface Coatings to Shot-Peening Qualification Sensitivity Fatigue Test Plan*

*Received from AMRDEC-AED, 10 Jan 2006.
This appendix appears in its original form, without editorial change.

AMSRD-AMR-AE-F-M 10 JAN 2006

MEMORANDUM FOR RECORD

Subject: Add Test Matrix for Aluminum Alloy with Surface Coatings to Shot Peening Qualification Sensitivity Fatigue Test Plan

1. Reference: AMSRD-AMR-AE-F Shot Peening Qualification Sensitivity Fatigue Test Plan, dated 3-June-05.

2. This memorandum revises reference 1 to the extent specified herein. It provides an additional testing matrix (Table 1) to evaluate the effect of shot peening and re-shot peening on fatigue strength of an aluminum alloy with surface coatings. This test program will result in a greater understanding the role of shot peening in depot overhaul and field repair of aluminum parts. Aluminum alloy, specimen preparation/machining, peening requirements, and test parameters to be used for this test program shall be same as these specified in Reference 1, but tensile properties shall be measured if the alloy at T73 condition was not heated treated in the same lot as that used in accordance with Reference 1. One test coupon geometry (Kt = 1.75) and ten fatigue tests are to be conducted for each of the 8 permutations for a total of 80 fatigue tests. Test results shall also be reported in accordance with Reference 1.

Table 1. Fatigue Test Matrix for Al 7075-T73 Alloy, Kt = 1.75, with Surface Coatings

Peening Intensity	Shot Peen Source	Anodize* Coating	Alodine** Coating	Re-Peening Anodized*** Surface, then Alodining
Unpeened	NA	10	10	NA
4 ± 0.5A	MIC	10	10	10
12 ± 0.5A	MIC	10	10	10

* Chromic acid anodize, Type I, Class 1, per MIL-A-8625F. Anodize coating shall be applied after shot peening.

** Alodine (chemical conversion coating), Class 1A, per MIL-C-5541. Alodine coating shall be applied after shot peening.

*** Re-peening anodized peened samples, then Alodining, Class 1A per MIL-C-5541.

3. The points of contact for this action are George Liu, tel. 256-313-8762, and Jung-Hua Chang, tel. 256-313-8745.

Mark S. Smith

Mark S. Smith
Chief, Structures and Materials Division
Aviation Engineering Directorate

Appendix B. Statement of Work for Determining Shot-Peening Intensities to Be Used in Shot-Peening Qualification Sensitivity Test Plan*

*Received from AMRDEC-AED, 23 May 2005.
This appendix appears in its original form, without editorial change.

13-July-2005

Statement of Work for Determination of Shot Peening Intensities to be Used in Shot Peening Qualification Sensitivity Test Plan

1. Reference: Shot Peening Qualification Sensitivity Fatigue Test Plan, 03-Jun-2005

2. Background Information:

This Statement Of Work (SOW) gives specific instructions regarding work pertaining to development/investigation of peening intensities that will be used on test specimens/coupons in Reference 1. The initial phase will consist of investigating the effects of varying specific shot peening parameters on Almen strips.

This study will investigate the 4 different media sizes and 3 different peening intensities specified in Reference 1 for shot peening performed In Accordance With (IAW) AMS-S-13165.

Final requirements for the peening intensities for all test specimens and material types in Reference 1 will be issued upon completion of all actions in this SOW and subsequent review by RDECOM Aviation Engineering Directorate (AED).

All parties (RDECOM AED, Army Research Laboratory (ARL), and Metal Improvement Corporation (MIC)) shall concur with items specified in this SOW prior to implementation/initiation of effort performed IAW this SOW.

Scope of Work:

Metal Improvement Company (MIC) shall **CONFIRM** that the MIC Bensalem, PA provided peening processes/parameters that will be used on the test specimens specified in Reference 1 are valid/correct. The provided peening parameters shall be verified via saturation curves and be capable of achieving the 200% coverage requirement specified for the test specimens in Reference 1. MIC shall inform ARL and RDECOM AED if changes to their predicted process are required to achieve the nominal peening intensities specified in Table 1. Tables 2, 3, 4 and 5 of this SOW are based upon information provided by MIC and may require modification if the parameters change from the MIC provided values. The peening parameters used to achieve the nominal peening intensities shall be varied as specified below in Tables 2 through 5 on the same shot peening machine and the results recorded. Each parameter in each table column shall be changed separately (and not in combination with any other listed or unspecified peening parameter) and shall be performed on a minimum of 3 Almen strips. When a specific parameter is changed or varied, the other 3 parameters shall be at the setting used to achieve the nominal intensity. Examples for Table 2, the 75° impingement Almen strips shall be peened at 45 psi, media flow rate of MIC TBD1 (MIC provided value), SOD of 7". For the air pressure column, the 36 psi Almen strip shall be peened at a 65° impingement angle, media flow of (MIC $TBD1_{70}$ lbs/min), Stand Off Distance (SOD) of 7". The modified media flow rate (MIC $TBD2_{70}$) Almen strips shall be peened at an impingement angle of 65°, air pressure of 45 psi, SOD 7". For the SOD column, the 9" SOD Almen strips shall be peened at impingement angle of 65°, air pressure of 45 psi,

media flow rate of MIC $TBD1_{70}$. The sequence shall be repeated in this manner for each value in a column and for Tables 3 through 5 of this SOW.

Table 1, Shot Media Sizes and Intensities

Shot Media Size	Associated Intensity	Nominal Intensity Requirement
S70	**5 to 11N**	**8N ± 0.5N**
S110	**8 to 12A**	**10A ± 0.5A**
S170	**8 to 12A**	**10A ± 0.5A**
S230	**10 to 12A**	**11A ± 0.5A**

Our intent is to approximately double the standard production tolerance(s) for a given peening parameter for each of the specified incremental variations. All 3 Almen strips for each of the 4 listed parameters shall be peened sequentially without further changes to the machine (including the nozzle) or other parameter settings. The peening time used shall be held constant at the "2T" time as determined by the applicable saturation curve. The intensity verification strips per paragraph 4.2 of AMS-S-13165 shall also be peened at the "2T" value prior to (and after) making the changes detailed below for each of the 4 parameters, however the minimum number of Almen strips peened shall be 3. Coverage on all Almen strips in this SOW shall be verified to be a minimum of 100% using either "Peenscan" or 10X visual inspection. All Almen strips in this SOW will be provided to ARL and will be made traceable to the peening parameters used for that particular Almen strip by labeling or other means. Record and report results from all testing performed, Appendix A of this SOW has data record sheets suggested for use for recording results from peening performed IAW Tables 2 through 5 of this SOW.

Table 2, S70 Media At 8N Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**45± 5** (nominal + tol)	**MIC $TBD1_{70}$**	**7** (nominal + tol)
75 ± 2°	36 ± 2	MIC $TBD2_{70}$	9 ± 0.25
85 ± 2°	30 ± 1.5	MIC $TBD3_{70}$	11 ± 0.25
90* ± 0.5°	54 ± 2.5		5 ± 0.25
55 ± 2°	63 ± 3		3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Table 3, S110 Media At 10A Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**80, -5** (nominal & tol)	**MIC TBD1$_{110}$**	**7** (nominal + tol)
75 ± 2°	64 ± 3	MIC TBD2$_{110}$	9 ± 0.25
85 ± 2°	48 ± 2.5	MIC TBD3$_{110}$	11 ± 0.25
90* ± 0.5°			5 ± 0.25
55 ± 2°			3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Table 4, S170 Media At 10A Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**75 ±5** (nominal & tol)	**MIC TBD1$_{170}$**	**7** (nominal + tol)
75 ± 2°	80 ± 4	MIC TBD2$_{170}$	9 ± 0.25
85 ± 2°	60 ± 3	MIC TBD3$_{170}$	11 ± 0.25
90* ± 0.5°	45 ± 2.5		5 ± 0.25
55 ± 2°			3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Table 5, S230 Media At 11A Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**55 ±5** (nominal & tol)	**MIC TBD1$_{230}$**	7 (nominal + tol)
75 ± 2°	66 ± 3.5	MIC TBD2$_{230}$	9 ± 0.25
85 ± 2°	77 ± 4	MIC TBD3$_{230}$	11 ± 0.25
90* ± 0.5°	44 ± 2.5		5 ± 0.25
55 ± 2°	33 ± 2		3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Notes for Tables 2 through 5:
General: Row with parameters shown in **BOLD** are settings used to achieve nominal peening intensity.
* Special emphasis on this impingement angle to determine the effect of shot "ricochet".

For Tables 2 through 5, there will be two more sets of Almen strips (3 strips per set) peened to determine the combined effect of the varying the four peening parameters specified in this statement of work, with the goal of achieving the highest and lowest possible "**production**" Almen intensities for each Table's specified intensity level. These Almen strips will be peened using parameter settings based on the possible variations in the actual (not multipled) production tolerances for a specific parameter. All parameter settings will be changed concurrently/simultaneously to the maximum specified/allowable production tolerance in an attempt to determine both the highest and the lowest peening intensity for the Almen strips from the combined changes. Previously performed testing per this SOW will be used to determine how the peening parameters are changed to achieve the high or low peening intensities. For the Table 2 example, if increasing the impingement angle (e.g. 70°), increasing the air pressure (e.g. 50 psi), decreasing the media flow rate (i.e. MIC TBD_{70} lbs/minute) and decreasing the nozzle distance (e.g. 6.75") **EACH/ALL** resulted in higher Almen intensities above, then these parameters would be changed simultaneously in that combination to determine the resultant effect on peening intensity. These parameters would then be similarly reversed to determine the lowest peening intensity.

Finally, for Tables 2 through 5, develop peening saturation curves that utilize the lowest impingement angles coupled with the "worst case" production parameters evaluated for each table to determine lowest achievable peening intensities when the worst case parameters are combined simultaneously. For example, again for Table 2, if combining the lowest impingement angle (25°), with the lowest production air pressure (nominal setting less the 10% tolerance (40 psi), with the highest media flow rate ("MIC TBD_{70}") and the highest production SOD (7.25") is expected to produce the lowest intensity, then that is how the parameters shall be combined.

3. The point of contact for this action is Randy McFarland, tel. (256) 313-8729.

Mark S. Smith 7-13-05
MARK S. SMITH
Chief, Structures and Materials Division

Appendix A

Test Record
S230 Media
10A to 12A Intensity

Test No. 51 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 55+/-5	Media Flow Rate (lbs/min) Nom. MIC $TBD1_{230}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 11A+/-.5A	Measured Intensity Nom. 11A+/-.5A	Measured Intensity Nom. 11A+/-.5A	Measured Intensity Nom. 11A+/-.5A	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	**65 +/-5 Nom.**	**55+/-5 Nom.**	**MIC $TBD1_{230}$**	**7 Nom.**					
A1	**90+/-0.5**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A2	**85+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A3	**75+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A4	**55+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A5	**45+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A6	**35+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A7	**25+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
B1	65 +/-5 Nom.	**77+/-4**	MIC $TBD1_{230}$	7 Nom.					
B2	65 +/-5 Nom.	**66+/-3.5**	MIC $TBD1_{230}$	7 Nom.					
B3	65 +/-5 Nom.	**44+/-2.5**	MIC $TBD1_{230}$	7 Nom.					
B4	65 +/-5 Nom.	**33+/-2**	MIC $TBD1_{230}$	7 Nom.					
C1	65 +/-5 Nom.	55+/-5 Nom.	**MIC $TBD2_{230}$**	7 Nom.					
C2	65 +/-5 Nom.	55+/-5 Nom.	**MIC $TBD3_{230}$**	7 Nom.					
D1	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**3+/-0.25**					
D2	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**5+/-0.25**					
D3	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**9+/-0.25**					
D4	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**11+/-0.25**					
Base Line **	**65 +/-5 Nom.**	**55+/-5 Nom.**	**MIC $TBD1_{230}$**	**7 Nom.**					

* Base Lines Not Included in Total Tests Count
** Either Saturation Curve or Intensity Verification Strips

Intensity Study, Table 5.

IntensityStudy.xls

Test Record
S170 Media
8A to 12A Intensity

Test No. 48 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 75+/-5	Media Flow Rate (lbs/min) Nom. MIC $TBD1_{170}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
A1	90+/-0.5	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
A2	85+/-2	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
A3	75+/-2	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
A4	55+/-2	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
A5	45+/-2	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
A6	35+/-2	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
A7	25+/-2	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					
B1	65 +/-5 Nom.	80+/-4	MIC $TBD1_{170}$	7 Nom.					
B2	65 +/-5 Nom.	60+/-3	MIC $TBD1_{170}$	7 Nom.					
B3	65 +/-5 Nom.	45+/-2.5	MIC $TBD1_{170}$	7 Nom.					
C1	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD2_{170}$	7 Nom.					
C2	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD3_{170}$	7 Nom.					
D1	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD1_{170}$	3+/-0.25					
D2	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD1_{170}$	5+/-0.25					
D3	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD1_{170}$	9+/-0.25					
D4	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD1_{170}$	11+/-0.25					
Base Line **	65 +/-5 Nom.	75+/-5 Nom.	MIC $TBD1_{170}$	7 Nom.					

* Base Lines Not Included in Total Tests Count
** Either Saturation Curve or Intensity Verification Strips

Intensity Study, Table 4.

IntensityStudy.xls

Test Record
S110 Media
8A to 12A Intensity

Test No. 45 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 80+0/-5	Media Flow Rate (lbs/min) Nom. MIC TBD1$_{110}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	**65 +/-5 Nom.**	80+0/-5 Nom.	**MIC TBD1$_{110}$**	**7 Nom.**					
A1	**90+/-0.5**	**80+0/-5 Nom.**	MIC TBD1$_{110}$	7 Nom.					
A2	**85+/-2**	**80+0/-5 Nom.**	MIC TBD1$_{110}$	7 Nom.					
A3	**75+/-2**	**80+0/-5 Nom.**	MIC TBD1$_{110}$	7 Nom.					
A4	**55+/-2**	**80+0/-5 Nom.**	MIC TBD1$_{110}$	7 Nom.					
A5	**45+/-2**	**80+0/-5 Nom.**	MIC TBD1$_{110}$	7 Nom.					
A6	**35+/-2**	**80+0/-5 Nom.**	MIC TBD1$_{110}$	7 Nom.					
A7	**25+/-2**	**80+0/-5 Nom.**	MIC TBD1$_{110}$	7 Nom.					
B1	65 +/-5 Nom.	**64+/-3**	MIC TBD1$_{110}$	7 Nom.					
B2	65 +/-5 Nom.	**48+/-2.5**	MIC TBD1$_{110}$	7 Nom.					
C1	65 +/-5 Nom.	**80+0/-5 Nom.**	**MIC TBD2$_{110}$**	7 Nom.					
C2	65 +/-5 Nom.	**80+0/-5 Nom.**	**MIC TBD3$_{110}$**	7 Nom.					
D1	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC TBD1$_{110}$	**3+/-0.25**					
D2	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC TBD1$_{110}$	**5+/-0.25**					
D3	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC TBD1$_{110}$	**9+/-0.25**					
D4	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC TBD1$_{110}$	**11+/-0.25**					
Base Line **	**65 +/-5 Nom.**	80+0/-5 Nom.	**MIC TBD1$_{110}$**	**7 Nom.**					

* Base Lines Not Included in Total Tests Count
** Saturation Curve or Intensity Verification Strips

Intensity Study, Table 3.

IntensityStudy.xls

Test Record
S70 Media
5N to 11N Intensity

Test No. 51 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 45+/-5	Media Flow Rate (lbs/min) Nom. MIC $TBD1_{70}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 8N+/-.5N	Measured Intensity Nom. 8N+/-.5N	Measured Intensity Nom. 8N+/-.5N	Measured Intensity Nom. 8N+/-.5N	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	**65 +/-5 Nom.**	**45+/-5 Nom.**	**MIC $TBD1_{70}$**	**7 Nom.**					
A1	**90+/-0.5**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A2	**85+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A3	**75+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A4	**55+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A5	**45+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A6	**35+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A7	**25+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
B1	65 +/-5 Nom.	**63+/-3**	MIC $TBD1_{70}$	7 Nom.					
B2	65 +/-5 Nom.	**54+/-2.5**	MIC $TBD1_{70}$	7 Nom.					
B3	65 +/-5 Nom.	**36+/-2**	MIC $TBD1_{70}$	7 Nom.					
B4	65 +/-5 Nom.	**30+/-1.5**	MIC $TBD1_{70}$	7 Nom.					
C1	65 +/-5 Nom.	45+/-5 Nom.	**MIC $TBD2_{70}$**	7 Nom.					
C2	65 +/-5 Nom.	45+/-5 Nom.	**MIC $TBD3_{70}$**	7 Nom.					
D1	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**3+/-0.25**					
D2	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**5+/-0.25**					
D3	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**9+/-0.25**					
D4	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**11+/-0.25**					
Base Line **	**65 +/-5 Nom.**	**45+/-5 Nom.**	**MIC $TBD1_{70}$**	**7 Nom.**					

* Base Lines Not Included in Total Tests Count
** Either Saturation Curve or Intensity Verification Strips

Intensity Study, Table 2.

IntensityStudy.xls

Appendix C. Statement of Work for Determining Shot-Peening Intensities to Be Used in Shot-Peening Qualification Sensitivity Test Plan*

*Received from AMRDEC-AED, 01 June 2005.
This appendix appears in its original form, without editorial change.

01-June-2005

Statement of Work for Determination of Shot Peening Intensities to be Used in Shot Peening Qualification Sensitivity Test Plan

1. Reference: Shot Peening Qualification Sensitivity Fatigue Test Plan, Undated.

2. Background Information:

This Statement Of Work (SOW) gives specific instructions regarding work pertaining to development/investigation of peening intensities that will be used on test specimens/coupons in Reference 1. The initial phase will consist of investigating the effects of varying specific shot peening parameters on Almen strips.

For this study, we have chosen to investigate the baseline peening specified in reference 1 for the titanium material (6Al-4V, Beta STOA condition) at two different primary intensity levels.

Final requirements for the peening intensities for all test specimens and material types in Reference 1 will be issued upon completion of all actions in this SOW and subsequent review by RDECOM Aviation Engineering Directorate (AED).

All parties (RDECOM AED, Army Research Laboratory (ARL), and MIC) shall concur with items specified in this SOW prior to implementation/initiation of effort performed In Accordance With (IAW) this SOW.

Scope of Work:

Metal Improvement Company (MIC) shall develop the peening processes that they intend to use on the test specimens specified in Reference 1. For the material mentioned above, Reference 1 requires shot peening at two different intensities IAW AMS-S-13165, the peening intensity of 8 to 12A requires use S170 cast steel shot and a coverage requirement of 200%. The second primary peening intensity is 5 to 11N using S70 cast steel shot, with a coverage requirement of 200%. This statement of work requires development of peening procedures that achieve nominal intensities of 10A ± 0.5A and 8N ± 0.5N for the applicable saturation curves. Upon successful completion of this requirement, MIC shall provide the process sheets (including all applicable production tolerances and settings for every peening parameter including those not mentioned in this SOW) used to achieve the nominal intensities to RDECOM AED for review. The peening parameters used to achieve the nominal peening intensities shall be varied as specified below on the same shot peening machine and the results recorded. Each parameter shall be changed separately (and not in combination with any other listed or unspecified peening parameter) and shall be performed on a minimum of 3 Almen strips. If the nominal peening parameter does not allow for the specified variation, advise RDECOM upon development of the nominal peening procedure prior to proceeding.

Scope of Work: (Continued)

Our intent is to approximately double the standard production tolerance(s) for a given peening parameter for each of the specified incremental variations. MIC shall inform RDECOM AED if a doubling of their production tolerances differs from the incremental variations listed below for impingement angle, air pressure and media flow rate. All 3 Almen strips for each of the 4 listed parameters shall be peened consequently without further changes to the machine (including the nozzle) or other parameter settings. The peening time used shall be held constant at the "2T" time as determined by the applicable saturation curve. The intensity verification strips per paragraph 4.2 of AMS-S-13165 shall be also be peened at the "2T" value prior to (and after) making the changes detailed below for each of the 4 parameters, however the minimum number of Almen strips peened shall be 3. Coverage on all Almen strips in this SOW shall be verified to be a minimum of 100% using either "Peenscan" or 10X visual inspection. All Almen strips in this SOW will be provided to ARL and will be made traceable to the peening parameters used for that particular Almen strip by labeling or other means.

Impingement Angle: Increase or decrease the peening angle from the nominal angle, in 10 degree increments (2 times production tolerance) to encompass a range of impingement angles from 20 to 90 °. For example, for a given impingement angle of 70 degrees (with a production tolerance of ± 5°), 3 each Almen strips would be peened at impingement angles of 80 and 90 degrees, as well as impingement angles from 60 to 20 degrees. If the nominal impingement angle used is 85 to 90 degrees, then the impingement angle shall be decreased only, in 10 degree increments to approximately 20 degrees.

Air Pressure: Increase and decrease the nominal air pressure, in two 20% increments. Example, 60 psi nominal pressure would be varied to pressures of 72 and 84 psi, as well as 48 and 36 psi.

Media Flow Rate: Increase the media flow rate to 120% and 140% of the nominal value. Then decrease the media flow rate to 80% and 60% of the nominal value.

Stand Off/ Nozzle Distance: Increase and decrease the nominal nozzle distances to 110% and 120% and 90%, and 80% respectively of the baseline value.
Note: Given the extremely precise requirements for nozzle positioning in the AMS shot peening spec (AMS 2432), of ±0.062", distance percentages were used rather than 0.125" increments since such small changes in nozzle distance would have a minimal effect on peening intensity.

The following table reflects previously provided information. Each of the listed parameter values are for illustrative purposes only and the tolerances shown are assumed to be representative of the production tolerances to be used by MIC in the peening of the test specimens/coupons in Reference 1.

Statement of Work for Determination of Shot Peening Intensities
to be Used in Shot Peening Qualification Sensitivity Test Plan

Scope of Work: (Continued)

The parameters in each column are to be varied independently, **NOT** in combination with values in adjacent columns and the sequence of varying a given parameter/column is at MIC's discretion.

Table 1, Example Listing of Nominal and Modified Peening Parameters

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
70 ± 5 (nom'l + tolerance)	**60± 6** (nominal + tol)	**10 ±1** (nominal + tol)	**10 ± 0.1**(nominal + tol)
80	72	12	11
90	84	14	12
60	48	8	9
50	36	6	8
40			
30			
20			

Finally, there will be four more sets of Almen strips (3 strips per set) peened to determine the combined effect of the varying the four peening parameters specified in this statement of work, with the goal of achieving the highest and lowest possible "production" Almen intensities for both the "A" and "N" intensity levels. These Almen strips will be peened using parameter settings based on the possible variations in the actual (not multipled) production tolerances for a specific parameter. This will result in 2 Almen strip sets (one "high", the other "low") being associated with each of the two peening intensities. All parameter settings will be changed concurrently/simultaneously to the maximum specified/allowable production tolerance in an attempt to determine both the highest and the lowest peening intensity for the Almen strips from the combined changes. For example, if increasing the impingement angle (e.g. 75°), increasing the air pressure (e.g. 66 psi), decreasing the media flow rate (i.e. 9 lbs/minute) and decreasing the nozzle distance (e.g. 9.9") **EACH/ALL** resulted in higher Almen intensities above, then these parameters would be changed simultaneously to determine the resultant combined effect on peening intensity. These parameters would then be similarly reversed to determine the lowest peening intensity.

3. The point of contact for this action is Randy McFarland, tel. (256) 313-8729.

Mark S. Smith

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Appendix D. Shot-Peening Qualification Sensitivity Fatigue Test Plan*

*Received from AMRDEC-AED, 03 June 2005.
This appendix appears in its original form, without editorial change.

Shot Peening Qualification Sensitivity Fatigue Test Plan

1.0 Background

Where shot peening is called out as a Critical Characteristic (CC) for critical safety items (CSI), it must be performed at an AMCOM approved source. The benefit to fatigue performance from shot peening is accounted for in the U.S. Army Helicopter safe-life design. Full scale component fatigue testing has been a qualification requirement for new shot peening sources. This work will result in a greater understanding of the effect of Almen intensity on the fatigue strength of the tested materials. Evaluation of this variability is essential to determine if new shot peening sources should be qualified by fatigue testing on a case-by-case basis. Results will be used to assess risk and to derive a safe life for discrepant parts.

2.0 Scope of Work

A. Materials and Shot Peening Vendor:

Army Research Lab (ARL) shall purchase the test materials and fabricate test samples. Metal Improvement Company (MIC) shall be used for shot peening. Materials and peening parameters to be used for the test program are as follows:

(1). Aluminum: Al7075-T73
Cast Steel Shot Size: S230
Intensity: 0.010 to 0.012 A
Coverage: 200 percent

(2). Titanium: Ti-6Al-4V Beta-solution and overaged
Cast Steel Shot Size: S170
Intensity: 0.008 to 0.012A
Coverage: 200 percent

(3). Titanium: Ti-6Al-4V Beta-solution and overaged
Cast Steel Shot Size: S70
Intensity: 0.005N to 0.011N
Coverage: 200 percent

(4). 9310 Steel (150-190 ksi)
Cast Steel Shot Size: S110
Intensity: 0.008 to 0.012 A
Coverage: 200 percent

(5). 4340 (150-170 ksi)
Cast Steel Shot Size: S110
Intensity: 0.008 to 0.012 A
Coverage: 200 percent

All material stock shall be from the same heat treat lots. Tensile properties shall be measured for all these materials. Test coupons and discs are to be machined to the same specifications from the same machining source. Shot peening shall be performed in accordance with AMS-S-13165. A shot peening plan shall be submitted and approved by AED prior to shot peening. After approval, the shot peening plan shall be frozen and followed for the peening of all test samples. Peening parameters (intensity, impingement angle, media flow, air pressure, etc.) shall be recorded for the peening of all specimen geometries, if possible.

B. Fatigue Testing:

ARL shall conduct axial fatigue tests (R=0.1, f = 20 Hz) at room temperature in air for each material listed in section 2A. Table 1 outlines the fatigue test matrix for Al7075-T73 alloy, 9310 steel, and 4340 steel. There are five shot peening intensity variables (include one unpeened condition) and three different test coupon geometries, one smooth ($K_t = 1$), and two notched ($K_t = 1.75$, $K_t = 2.5$). Ten fatigue tests are to be conducted for each of the 15 permutations for a total of 150 fatigue tests per material.

Table 1. Fatigue Test Matrix for Al7075-T73 Alloy, 9310 Steel, and 4340 Steel

Peening Variable (Intensity*)	$K_t = 1$	$K_t = 1.75$	$K_t = 2.5$
Not peened	10	10	10
Low 1	10	10	10
Low 2	10	10	10
High 1	10	10	10
High 2	10	10	10

Table 2 outlines the fatigue test matrix for Ti-6Al-4V Beta-solution and overaged alloy. Two different peening intensity levels (A and N) shall be evaluated. There are nine shot peening intensity variables (including one unpeened condition) and three different test coupon geometries, one smooth ($K_t = 1$), and two notched ($K_t = 1.75$, $K_t = 2.5$). A total of 240 fatigue test coupons shall be tested.

Note that for all fatigue tests, the cutoff (or stop point) is 10^7 cycles.

Table 2. Fatigue Test Matrix for Ti-6Al-4V Beta-Solution and Overaged Alloy

Peening Variable (Intensity*)	$K_t = 1$	$K_t = 1.75$	$K_t = 2.5$
Not peened	8	8	8
Low 1 (A intensity)	9	9	9
Low 2 (A intensity)	9	9	9
High 1 (A intensity)	9	9	9
High 2 (A intensity)	9	9	9
Low 1 (N intensity)	9	9	9
Low 2 (N intensity)	9	9	9
High 1 (N intensity)	9	9	9
High 2 (N intensity)	9	9	9

* Based on the Almen strip intensity study at MIC, ARL shall coordinate with AED and MIC to develop shot peening processing details affecting peening intensity for the intensity used on the fatigue coupons.

C. Residual Stress and Work Hardening Measurement

(1). In addition to fatigue coupons, disk samples, 1 inch in diameter and 0.375 inch in thickness, shall be sectioned from the round stock used for fatigue test coupons. For each test material item listed in section 2A, three of these disks shall be prepared for each peening variable (reference column one of Table 1 and Table 2). A total of 72 disks shall be manufactured. X-Ray diffraction shall be used to generate residual stress and work hardening profiles as a function of depth. These profiles shall be generated at two locations per disk. A profile consists of 6 measurements, one taken at the surface, and one each at depths of one (1), two (2), five (5), seven (7), and ten (10) mils.

(2). In addition, nine additional disks of 9310 steel shall be prepared and carburized. Three of the disks shall be peened to the nominal intensity for the intensity range specified for 9310 steel listed in section 2.A, three shall be peened to a low intensity (to be determined in the test plan), and the remaining three shall not be peened. As before, a profile shall be generated at two locations on each disk. A profile for these disks requires six measurements; one taken at the surface, and one each at depths of one (1), two (2), three (3), five (5), and seven (7) mils.

D. Surface Roughness Measurement

Surface roughness shall be measured by laser surface profilometry. Surface roughness shall be measured for each of the peening variable (reference column one of Table 1 and Table 2), for two peening geometries (the smooth fatigue coupon, ($K_t = 1$), and the disk sample described in section 2C), and at three different locations on each sample. Two samples shall be measured for each of the two peening geometries described above. A total of 288 surface roughness measurements shall be taken.

E. Post Test Metallurgical Evaluation

If the sample shows a significant drop in fatigue strength, ARL may need to perform metallurgical evaluation of the tested sample to identify the root cause of failure.

3.0 Deliverables

A. ARL shall develop a test plan detailing all activities, test parameters, and analyses. This test plan shall be developed in consultation with AMSRD-AMR -AE-P and AMSRD-AMR-AE-F. Technical points of contact are: for AMSRD-AMR-AE-F, George Liu (256-313-8762) or Jung-Hua Chang (256-313-8745), for AMSRD-AMR-AE-P, Glenn Sahrmann (256-319-5256).

B. ARL shall submit a report that includes all tensile and fatigue test results, residual stress profiles, work hardening measurements, surface roughness measurements, fatigue curve analyses (curve shape, mean, coefficient of variation, etc), and evaluations.

Mark S. Smith

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Aviation Engineering Directorate

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Appendix E. Statement of Work for Determining Shot-Peening Intensities to Be Used in Shot-Peening Qualification Sensitivity Test Plan*

*Received from AMRDEC-AED, 13 July 2005.
This appendix appears in its original form, without editorial change.

13-July-2005

Statement of Work for Determination of Shot Peening Intensities to be Used in Shot Peening Qualification Sensitivity Test Plan

1. Reference: Shot Peening Qualification Sensitivity Fatigue Test Plan, 03-Jun-2005

2. Background Information:

This Statement Of Work (SOW) gives specific instructions regarding work pertaining to development/investigation of peening intensities that will be used on test specimens/coupons in Reference 1. The initial phase will consist of investigating the effects of varying specific shot peening parameters on Almen strips.

This study will investigate the 4 different media sizes and 3 different peening intensities specified in Reference 1 for shot peening performed In Accordance With (IAW) AMS-S-13165.

Final requirements for the peening intensities for all test specimens and material types in Reference 1 will be issued upon completion of all actions in this SOW and subsequent review by RDECOM Aviation Engineering Directorate (AED).

All parties (RDECOM AED, Army Research Laboratory (ARL), and Metal Improvement Corporation (MIC)) shall concur with items specified in this SOW prior to implementation/initiation of effort performed IAW this SOW.

Scope of Work:

Metal Improvement Company (MIC) shall **CONFIRM** that the MIC Bensalem, PA provided peening processes/parameters that will be used on the test specimens specified in Reference 1 are valid/correct. The provided peening parameters shall be verified via saturation curves and be capable of achieving the 200% coverage requirement specified for the test specimens in Reference 1. MIC shall inform ARL and RDECOM AED if changes to their predicted process are required to achieve the nominal peening intensities specified in Table 1. Tables 2, 3, 4 and 5 of this SOW are based upon information provided by MIC and may require modification if the parameters change from the MIC provided values. The peening parameters used to achieve the nominal peening intensities shall be varied as specified below in Tables 2 through 5 on the same shot peening machine and the results recorded. Each parameter in each table column shall be changed separately (and not in combination with any other listed or unspecified peening parameter) and shall be performed on a minimum of 3 Almen strips. When a specific parameter is changed or varied, the other 3 parameters shall be at the setting used to achieve the nominal intensity. Examples for Table 2, the 75° impingement Almen strips shall be peened at 45 psi, media flow rate of MIC TBD1 (MIC provided value), SOD of 7". For the air pressure column, the 36 psi Almen strip shall be peened at a 65° impingement angle, media flow of (MIC $TBD1_{70}$ lbs/min), Stand Off Distance (SOD) of 7". The modified media flow rate (MIC $TBD2_{70}$) Almen strips shall be peened at an impingement angle of 65°, air pressure of 45 psi, SOD 7". For the SOD column, the 9" SOD Almen strips shall be peened at impingement angle of 65°, air pressure of 45 psi,

media flow rate of MIC $TBD1_{70}$. The sequence shall be repeated in this manner for each value in a column and for Tables 3 through 5 of this SOW.

Table 1, Shot Media Sizes and Intensities

Shot Media Size	Associated Intensity	Nominal Intensity Requirement
S70	**5 to 11N**	**8N ± 0.5N**
S110	**8 to 12A**	**10A ± 0.5A**
S170	**8 to 12A**	**10A ± 0.5A**
S230	**10 to 12A**	**11A ± 0.5A**

Our intent is to approximately double the standard production tolerance(s) for a given peening parameter for each of the specified incremental variations. All 3 Almen strips for each of the 4 listed parameters shall be peened sequentially without further changes to the machine (including the nozzle) or other parameter settings. The peening time used shall be held constant at the "2T" time as determined by the applicable saturation curve. The intensity verification strips per paragraph 4.2 of AMS-S-13165 shall also be peened at the "2T" value prior to (and after) making the changes detailed below for each of the 4 parameters, however the minimum number of Almen strips peened shall be 3. Coverage on all Almen strips in this SOW shall be verified to be a minimum of 100% using either "Peenscan" or 10X visual inspection. All Almen strips in this SOW will be provided to ARL and will be made traceable to the peening parameters used for that particular Almen strip by labeling or other means. Record and report results from all testing performed, Appendix A of this SOW has data record sheets suggested for use for recording results from peening performed IAW Tables 2 through 5 of this SOW.

Table 2, S70 Media At 8N Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**45± 5** (nominal + tol)	**MIC $TBD1_{70}$**	**7** (nominal + tol)
75 ± 2°	36 ± 2	MIC $TBD2_{70}$	9 ± 0.25
85 ± 2°	30 ± 1.5	MIC $TBD3_{70}$	11 ± 0.25
90* ± 0.5°	54 ± 2.5		5 ± 0.25
55 ± 2°	63 ± 3		3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Table 3, S110 Media At 10A Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**80, -5** (nominal & tol)	**MIC $\mathbf{TBD1_{110}}$**	**7** (nominal + tol)
75 ± 2°	64 ± 3	MIC $TBD2_{110}$	9 ± 0.25
85 ± 2°	48 ± 2.5	MIC $TBD3_{110}$	11 ± 0.25
90* ± 0.5°			5 ± 0.25
55 ± 2°			3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Table 4, S170 Media At 10A Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**75 ±5** (nominal & tol)	**MIC $\mathbf{TBD1_{170}}$**	**7** (nominal + tol)
75 ± 2°	80 ± 4	MIC $TBD2_{170}$	9 ± 0.25
85 ± 2°	60 ± 3	MIC $TBD3_{170}$	11 ± 0.25
90* ± 0.5°	45 ± 2.5		5 ± 0.25
55 ± 2°			3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Table 5, S230 Media At 11A Nominal Intensity

Impingement angle (degree)	Air pressure (psi)	Media Flow Rate (lbs/minute)	Nozzle Distance (inches)
65 ± 5 (nom'l + tolerance)	**55 ±5** (nominal & tol)	**MIC $\mathbf{TBD1_{230}}$**	**7** (nominal + tol)
75 ± 2°	66 ± 3.5	MIC $TBD2_{230}$	9 ± 0.25
85 ± 2°	77 ± 4	MIC $TBD3_{230}$	11 ± 0.25
90* ± 0.5°	44 ± 2.5		5 ± 0.25
55 ± 2°	33 ± 2		3 ± 0.25
45 ± 2°			
35 ± 2°			
25 ± 2°			

Notes for Tables 2 through 5:
General: Row with parameters shown in **BOLD** are settings used to achieve nominal peening intensity.
* Special emphasis on this impingement angle to determine the effect of shot "ricochet".

For Tables 2 through 5, there will be two more sets of Almen strips (3 strips per set) peened to determine the combined effect of the varying the four peening parameters specified in this statement of work, with the goal of achieving the highest and lowest possible "**production**" Almen intensities for each Table's specified intensity level. These Almen strips will be peened using parameter settings based on the possible variations in the actual (not multipled) production tolerances for a specific parameter. All parameter settings will be changed. concurrently/simultaneously to the maximum specified/allowable production tolerance in an attempt to determine both the highest and the lowest peening intensity for the Almen strips from the combined changes. Previously performed testing per this SOW will be used to determine how the peening parameters are changed to achieve the high or low peening intensities. For the Table 2 example, if increasing the impingement angle (e.g. 70°), increasing the air pressure (e.g. 50 psi), decreasing the media flow rate (i.e. MIC TBD_{70} lbs/minute) and decreasing the nozzle distance (e.g. 6.75") **EACH/ALL** resulted in higher Almen intensities above, then these parameters would be changed simultaneously in that combination to determine the resultant effect on peening intensity. These parameters would then be similarly reversed to determine the lowest peening intensity.

Finally, for Tables 2 through 5, develop peening saturation curves that utilize the lowest impingement angles coupled with the "worst case" production parameters evaluated for each table to determine lowest achievable peening intensities when the worst case parameters are combined simultaneously. For example, again for Table 2, if combining the lowest impingement angle (25°), with the lowest production air pressure (nominal setting less the 10% tolerance (40 psi), with the highest media flow rate ("MIC TBD_{70}") and the highest production SOD (7.25") is expected to produce the lowest intensity, then that is how the parameters shall be combined.

3. The point of contact for this action is Randy McFarland, tel. (256) 313-8729.

Mark S. Smith 7-13-05

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Chief, Structures and Materials Division

Appendix A

Test Record
S70 Media
5N to 11N Intensity

Test No. 51 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 45+/-5	Media Flow Rate (lbs/min) Nom. MIC $TBD1_{70}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 8N+/-.5N	Measured Intensity Nom. 8N+/-.5N	Measured Intensity Nom. 8N+/-.5N	Measured Intensity Nom. 8N+/-.5N	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	**65 +/-5 Nom.**	**45+/-5 Nom.**	**MIC $TBD1_{70}$**	**7 Nom.**					
A1	**90+/-0.5**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A2	**85+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A3	**75+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A4	**55+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A5	**45+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A6	**35+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
A7	**25+/-2**	45+/-5 Nom.	MIC $TBD1_{70}$	7 Nom.					
B1	65 +/-5 Nom.	**63+/-3**	MIC $TBD1_{70}$	7 Nom.					
B2	65 +/-5 Nom.	**54+/-2.5**	MIC $TBD1_{70}$	7 Nom.					
B3	65 +/-5 Nom.	**36+/-2**	MIC $TBD1_{70}$	7 Nom.					
B4	65 +/-5 Nom.	**30+/-1.5**	MIC $TBD1_{70}$	7 Nom.					
C1	65 +/-5 Nom.	45+/-5 Nom.	**MIC $TBD2_{70}$**	7 Nom.					
C2	65 +/-5 Nom.	45+/-5 Nom.	**MIC $TBD3_{70}$**	7 Nom.					
D1	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**3+/-0.25**					
D2	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**5+/-0.25**					
D3	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**9+/-0.25**					
D4	65 +/-5 Nom.	45+/-5 Nom.	MIC $TBD1_{70}$	**11+/-0.25**					
Base Line **	**65 +/-5 Nom.**	**45+/-5 Nom.**	**MIC $TBD1_{70}$**	**7 Nom.**					

* Base Lines Not Included in Total Tests Count
** Either Saturation Curve or Intensity Verification Strips

Intensity Study, Table 2.

IntensityStudy.xls

Test Record
S110 Media
8A to 12A Intensity

Test No. 45 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 80+0/-5	Media Flow Rate (lbs/min) Nom. MIC $TBD1_{110}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	**65 +/-5 Nom.**	**80+0/-5 Nom.**	**MIC $TBD1_{110}$**	**7 Nom.**					
A1	**90+/-0.5**	**80+0/-5 Nom.**	MIC $TBD1_{110}$	7 Nom.					
A2	**85+/-2**	**80+0/-5 Nom.**	MIC $TBD1_{110}$	7 Nom.					
A3	**75+/-2**	**80+0/-5 Nom.**	MIC $TBD1_{110}$	7 Nom.					
A4	**55+/-2**	**80+0/-5 Nom.**	MIC $TBD1_{110}$	7 Nom.					
A5	**45+/-2**	**80+0/-5 Nom.**	MIC $TBD1_{110}$	7 Nom.					
A6	**35+/-2**	**80+0/-5 Nom.**	MIC $TBD1_{110}$	7 Nom.					
A7	**25+/-2**	**80+0/-5 Nom.**	MIC $TBD1_{110}$	7 Nom.					
B1	65 +/-5 Nom.	**64+/-3**	MIC $TBD1_{110}$	7 Nom.					
B2	65 +/-5 Nom.	**48+/-2.5**	MIC $TBD1_{110}$	7 Nom.					
C1	65 +/-5 Nom.	**80+0/-5 Nom.**	**MIC $TBD2_{110}$**	7 Nom.					
C2	65 +/-5 Nom.	**80+0/-5 Nom.**	**MIC $TBD3_{110}$**	7 Nom.					
D1	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC $TBD1_{110}$	**3+/-0.25**					
D2	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC $TBD1_{110}$	**5+/-0.25**					
D3	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC $TBD1_{110}$	**9+/-0.25**					
D4	65 +/-5 Nom.	**80+0/-5 Nom.**	MIC $TBD1_{110}$	**11+/-0.25**					
Base Line **	**65 +/-5 Nom.**	80+0/-5 Nom.	**MIC $TBD1_{110}$**	**7 Nom.**					

* Base Lines Not Included in Total Tests Count
** Saturation Curve or Intensity Verification Strips

Test Record
S170 Media
8A to 12A Intensity

Test No. 48 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 75+/-5	Media Flow Rate (lbs/min) Nom. MIC $TBD1_{170}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Measured Intensity Nom. 10A+/-.5A	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	**65 +/-5 Nom.**	**75+/-5 Nom.**	**MIC $TBD1_{170}$**	**7 Nom.**					
A1	**90+/-0.5**	**75+/-5 Nom.**	MIC $TBD1_{170}$	7 Nom.					
A2	**85+/-2**	**75+/-5 Nom.**	MIC $TBD1_{170}$	7 Nom.					
A3	**75+/-2**	**75+/-5 Nom.**	MIC $TBD1_{170}$	7 Nom.					
A4	**55+/-2**	**75+/-5 Nom.**	MIC $TBD1_{170}$	7 Nom.					
A5	**45+/-2**	**75+/-5 Nom.**	MIC $TBD1_{170}$	7 Nom.					
A6	**35+/-2**	**75+/-5 Nom.**	MIC $TBD1_{170}$	7 Nom.					
A7	**25+/-2**	**75+/-5 Nom.**	MIC $TBD1_{170}$	7 Nom.					
B1	65 +/-5 Nom.	**80+/-4**	MIC $TBD1_{170}$	7 Nom.					
B2	65 +/-5 Nom.	**60+/-3**	MIC $TBD1_{170}$	7 Nom.					
B3	65 +/-5 Nom.	**45+/-2.5**	MIC $TBD1_{170}$	7 Nom.					
C1	65 +/-5 Nom.	**75+/-5 Nom.**	**MIC $TBD2_{170}$**	7 Nom.					
C2	65 +/-5 Nom.	**75+/-5 Nom.**	**MIC $TBD3_{170}$**	7 Nom.					
D1	65 +/-5 Nom.	**75+/-5 Nom.**	MIC $TBD1_{170}$	**3+/-0.25**					
D2	65 +/-5 Nom.	**75+/-5 Nom.**	MIC $TBD1_{170}$	**5+/-0.25**					
D3	65 +/-5 Nom.	**75+/-5 Nom.**	MIC $TBD1_{170}$	**9+/-0.25**					
D4	65 +/-5 Nom.	**75+/-5 Nom.**	MIC $TBD1_{170}$	**11+/-0.25**					
Base Line **	**65 +/-5 Nom.**	**75+/-5 Nom.**	**MIC $TBD1_{170}$**	**7 Nom.**					

* Base Lines Not Included in Total Tests Count
** Either Saturation Curve or Intensity Verification Strips

Intensity Study, Table 4.

IntensityStudy.xls

Test Record
S230 Media
10A to 12A Intensity

Test No. 51 Total Tests* 3 Min. Per Row	Impingement Angle (degree) Nom. 65+/-5	Air Pressure (psi) Nom. 55+/-5	Media Flow Rate (lbs/min) Nom. MIC $TBD1_{230}$	Nozzle Distance (inches) Nom. 7 +/-0.25	Measured Intensity Nom. 11A+/-.5A	Measured Intensity Nom. 11A+/-.5A	Measured Intensity Nom. 11A+/-.5A	Measured Intensity Nom. 11A+/-.5A	Average Intensity (N,A)
	A	B	C	D	Record Results	Record Results	Record Results	Record Results, If Needed	Record Results, Optional
Base Line **	**65 +/-5 Nom.**	**55+/-5 Nom.**	**MIC $TBD1_{230}$**	**7 Nom.**					
A1	**90+/-0.5**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A2	**85+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A3	**75+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A4	**55+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A5	**45+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A6	**35+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
A7	**25+/-2**	55+/-5 Nom.	MIC $TBD1_{230}$	7 Nom.					
B1	65 +/-5 Nom.	**77+/-4**	MIC $TBD1_{230}$	7 Nom.					
B2	65 +/-5 Nom.	**66+/-3.5**	MIC $TBD1_{230}$	7 Nom.					
B3	65 +/-5 Nom.	**44+/-2.5**	MIC $TBD1_{230}$	7 Nom.					
B4	65 +/-5 Nom.	**33+/-2**	MIC $TBD1_{230}$	7 Nom.					
C1	65 +/-5 Nom.	55+/-5 Nom.	**MIC $TBD2_{230}$**	7 Nom.					
C2	65 +/-5 Nom.	55+/-5 Nom.	**MIC $TBD3_{230}$**	7 Nom.					
D1	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**3+/-0.25**					
D2	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**5+/-0.25**					
D3	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**9+/-0.25**					
D4	65 +/-5 Nom.	55+/-5 Nom.	MIC $TBD1_{230}$	**11+/-0.25**					
Base Line **	**65 +/-5 Nom.**	**55+/-5 Nom.**	**MIC $TBD1_{230}$**	**7 Nom.**					

* Base Lines Not Included in Total Tests Count
** Either Saturation Curve or Intensity Verification Strips

Intensity Study, Table 5.

IntensityStudy.xls

Appendix F. Memorandum for Record, Modifications to Shot-Peening Qualification Sensitivity Fatigue Test Plan*

*Received from AMRDEC-AED, 06 September 2005.
This appendix appears in its original form, without editorial change.

AMSRD-AMR-AE-F-M 06 September 2005

MEMORANDUM FOR RECORD

Subject: Modifications to Shot Peening Qualification Sensitivity Fatigue Test Plan

1. Reference: AMSRD-AMR-AE-F Shot Peening Qualification Sensitivity Fatigue Test Plan, dated 3-June-05

2. This memorandum revises reference 1 to the extent specified herein. It provides the specific shot peening intensities to be used on the fatigue coupons and disk samples in Reference 1. This memorandum also adds the requirement to shot peen **additional** fatigue coupons **and disks** as detailed herein. The additional specimens are to be tested/evaluated in the same manner as specified in Ref. 1 for the baseline coupons/samples, but each sources results shall be reported separately. The intensity values herein were determined from the completed SOW for Determination of Shot Peening Intensities to be Used in Shot Peening Qualification Sensitivity Test Plan, dated 13-July-05.

Table 1, Fatigue Test Matrix for 4340 Alloy

Peening Intensity	Shot Peen Source(s)	$K_t = 1$	$K_t = 1.75$	$K_t = 2.5$
Unpeened	NA	10	10	10
Low 1, 4A	MIC	10	10	10
Low 2, 8A	MIC & CCAD	10	10	10
High 1, 12A	CCAD	10	10	10
High 2, 14A (-0, +0.5)	CCAD	10	10	10

Note: For the 8A peening intensity (Low 2), Metal Improvement Corp. (MIC) will shot peen a total of 30 coupons (10 at each Kt value) and 3 disk samples and Corpus Christi Army Depot (CCAD) will also shot peen a total of 30 coupons (10 at each Kt value) and 3 disk coupons. This criteria also applies for 9310 alloy table below.

Table 2, Fatigue Test Matrix for 9310 Alloy

Peening Intensity	Shot Peen Source(s)	$K_t = 1$	$K_t = 1.75$	$K_t = 2.5$
Unpeened	NA	10	10	10
Low 1, 4A	MIC	10	10	10
Low 2, 8A	MIC & CCAD	10	10	10
High 1, 12A	CCAD	10	10	10
High 2, 14A (-0, +0.5)	CCAD	10	10	10

Subject: Modifications to Shot Peening Qualification Sensitivity Fatigue Test Plan

Table 3, Fatigue Test Matrix for 7075-T73 Aluminium Alloy

Peening Intensity	Shot Peen Source(s)	$K_t = 1$	$K_t = 1.75$	$K_t = 2.5$
Unpeened	NA	10	10	10
Low 1, 4A	MIC	10	10	10
Low 2, 10A	MIC & CCAD	10	10	10
High 1, 12A	MIC & CCAD	10	10	10
High 2, 14A (-0, +0.5A)	MIC	10	10	10

Note for Al 7075-T73 Table: If a row indicates two shot peen sources, then 10 specimens for each Kt value shall be shot peened at each source at the specified intensities, e.g. for the 10A peening intensity, MIC shall shot peen a total of 30 specimens at that intensity (and 3 disk samples), and CCAD shall shot peen a total of 30 specimens at that intensity (10 at each Kt level and as well as 3 disks). Repeat for the 12A intensity.

Table 4, Fatigue Test Matrix for Ti-6Al-4V Beta-Solution and Overaged Alloy

Peening Intensity	Shot Peen Source	$K_t = 1$	$K_t = 1.75$	$K_t = 2.5$
Unpeened	NA	8	8	8
Low 1, 3N	MIC	9	9	9
Low 2, 5N	MIC	9	9	9
High 1, 11N	MIC	9	9	9
High 2, 14N	MIC	9	9	9
Low 1, 4A	MIC	9	9	9
Low 2, 8A	MIC	9	9	9
High 1, 11.5A, (-0, +0.5A)	MIC	9	9	9
High 2, 14A (-0, +0.5A)	CCAD	9	9	9

Note for All Tables: All intensity values in the tables above are ± 0.5 of the base N or A intensity value, unless otherwise specified. Additional tables were used in this memorandum since it was impractical to synchronize these tables with those originally specified in Reference 1.

3. The points of contact for this action are Randy McFarland, tel. 313-8729 or George Liu, tel. 313-8762.

Mark S. Smith
Chief, Structures and Materials Division
Aviation Engineering Directorate

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